COMPUTER SUPPORTED COLLABORATIVE ENVIRONMENT FOR VIRTUAL SIMULATION OF RADIATION TREATMENT PLANNING

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Abstract-**A collaborative environment for virtual simulation in radiotherapy treatment planning is presented. The environment architecture is based on both off-line and on-line communication of data under a secure framework and can be directly integrated into the infrastructure of a radiotherapy department. The on-line collaboration is based on the simultaneous execution of all actions at both collaborating sites, and prerequisites the off-line communication of the data set on which the collaboration will be performed. A technical pilot study has been carried out on clinical sites, monitoring the performance of the implementation, and revealed high interactivity during an on-line collaboration session.**

Keywords **– Telemedicine, CSCW, Radiation Treatment Planning, data security.**

I. INTRODUCTION

Treatment Planning, in general, is the process that involves the determination of treatment parameters considered optimal in the management of patient's disease. In external beam radiotherapy treatment planning is a procedure comprising a number of activities, which follow from the decision to treat a patient with radiotherapy and from the stated objectives of that treatment [1]. The entire procedure, called Radiation Treatment Planning (RTP), is of high complexity, and the use of dedicated hardware and specialized software is required, in order to be feasible for the healthcare professionals to achieve a reasonable, or sometimes optimal treatment plan.

The activities involved in the RTP procedure include the definition of treatment volumes, the design of beams' geometry, the prescription of a radiation dose, and the evaluation of the treatment plan. Conventional techniques make use of the treatment simulator, the main function of which is to display the treatment fields so that the target volume may be accurately encompassed, without delivering excessive irradiation to surrounding healthy tissues. This goal is achieved using real-time fluoroscopic imaging of internal organs leading to the correct positioning of fields and shielding blocks, in relation to external landmarks [2].

Alternatively, the simulator machine can be replaced by the Virtual Simulator (VS), a software system that uses patient's tomographic data (CT or MRI), instead of the real patient, enabling health care professional firstly, to delineate the target volume and other critical organs, and secondly to place the irradiation fields. The results of the design on the VS can then be passed to dose calculation routines, and to dose distributions' evaluation and optimisation modules. Under this application scenario, the use of treatment simulator machine is limited to the verification procedure of complex cases, adding confidence to the planning process.

Even though the availability of three dimensional (3-D) visualisation techniques, as well as image processing tools, facilitates the design of the plan on the VS, the complexity of the problem of defining an optimal treatment plan remains significant and the need of a "second opinion" from experts of the field is apparent. At this point, the benefits from the employment of the VS in the RTP procedure are highlighted, since the "virtualisation" of the complete RTP procedure enables the availability of the virtual patient on different sites than those of its physical location [3][4]. Moreover, putting into practice the continuous advances in telecommunications, which have contributed vastly in the establishment of teleradiology networks [5][6], the real time information flow can overpass the limits of the Local Area Network (LAN) of a clinic, and collaboration between institutions can be realised. Thus, with the introduction of VS, a wide area of possible telematics applications in radiation oncology is initiated [7][8].

In this paper, the VS called GALINOS that supports on-line tele-collaboration between health care professionals is presented. A general overview of the functionalities provided by the stand alone VS is given, followed by the architecture description of the collaborative environment, and the evaluation results of the technical pilot study.

II. METHODOLOGY

The aim of VS is to provide health care professionals with the required tools in order to carry out firstly, target volume and other critical organs delineation, and secondly, irradiation fields' placement. Furthermore, the interoperability of the VS with tomographic scanners and PACS, from which it receives data, and with the dose calculation routines, to which the results of the design are sent, must be assured.

The connectivity of GALINOS VS with devices found in a radiation oncology department is accomplished using the DICOM standard [9]. More specifically, the GALINOS VS is capable of importing tomographic data in DICOM format, while data output, concerning anatomical structure description, beam placement and radiotherapy related images, is encoded according to the radiotherapy (RT) extensions of the DICOM standard.

The architecture design of the stand-alone VS system is performed in accordance with the dual aim of the VS system, hence two interfaces are incorporated: one dedicated to anatomical description, and one dedicated to beam description. Both of these interfaces interact with the GALINOS database, where all of the required data is stored.

The collaborative environment of GALINOS VS extends the capabilities of the stand-alone VS, giving the opportunity to remote health care professionals to collaborate in the delineation of anatomical structures of interest and in the placement of irradiation fields. The implementation is based on a point-to-point communication

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle Computer Supported Collaborative Environment for Virtual Simulation of Radiation Treatment Planning	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Department of Electrical and Computer Engineering National Technical University of Athens Athens, Greece	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-26, 2001 held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 4	

scheme and the main concept of the environment is to synchronise the two VS, in order to provide the collaborating parties with the same view of the application. The indispensable condition for the realisation of a collaboration session is that both collaborating parties possess the same data set, on which the plan design will be performed. Upon this condition, all the functionalities provided by the stand-alone VS can be simultaneously executed in a collaborative environment. The term "data set", in the case of GALINOS collaborative environment, includes patient demographic information, a set of tomographic images and information related with their acquisition (pixel spacing, slice position, etc). The proposed scenario, is decomposed into the following steps:

- A data set is scheduled to be communicated between the collaborating parties.
- The transfer of the data set takes place.
- A collaboration request is sent from one party to the other.
- In case of request's approval the on-line collaboration session begins and the VSs of the collaborating parties are initialised to the state of the VS of the calling party.
- On-line collaboration takes place, with the two parties sharing the same view of the VS, while voice communication is also provided.
- The collaboration session ends, upon request of one of the collaborating parties.

In order to realise the above scenario both asynchronous (off-line transfer of data sets) and synchronous (on-line collaboration) data exchange schemes are employed, while special attention is given to security issues, which are raised by the introduction of tele-cooperative functionalities. In a more concrete way, the information manipulated by the VS contains many data related directly to identifiable persons, their illnesses and their treatment. Therefore, the introduction of electronic processing and transferring of such information, through the tele-cooperative work in VS, should be directly followed by the implementation of a security framework, which eliminates any possible violations of the authenticity, integrity, confidentiality and availability of data [10][11].

A. Off-line transfer of data sets

Collaboration on anatomical and beam description design prerequisites a successful communication of the data set, on which the design will be based, between the collaborating parties. Data transfer is usually performed off-line, considering the size of the communicated data set, which can range from 5 to 25 Mbytes after compression (depending on the number of tomographic images). To this end, the user can schedule data exchange jobs, which are stored in GALINOS database, and include the location of the receiving party, an identifier for the data set that is going to be sent and the scheduled time for the delivery. These data exchange jobs are handled by a custom-built data exchange service. The role of the service is to send/receive data sets to/from different workstations running GALINOS VS without any intervention by the user. At any given instance the service is in one of the following modes: idle, sending or receiving mode.

As shown in Fig. 1 the service is composed by four distinct layers, each one responsible for a different task. The specific partition of service's architecture is implied by the discrete functionalities of the service and is used for the independent implementation and redesign of every layer.

The data layer is responsible for the communication with the GALINOS database. If the service is in idle mode the data layer performs a periodic monitoring regarding the presence of a data exchange job. Whenever the scheduled time for a data exchange job arrives, the data layer sets the service into sending mode and assembles the required data set from the database. The data set is then forwarded to the compression layer. In the case where the service is in receiving mode, the data layer receives a data set from the compression layer and stores the contained data in database.

In the compression layer the lossless Huffman algorithm is used for the compression/decompression of the relative data, conducting the result to the security or the data layer respectively.

The fulfilment of the requirements of *confidentiality*, defending the privacy of the treated patient, *integrity*, preventing changes or damages of the communicated data and *authenticity of data*, ensuring that the communicated data is "genuine", is achieved with the employment of encryption techniques, digital signatures and certificates in the security layer. Furthermore, *audit trails* are maintained through the chronological recording of all transactions. The security approach, which has been employed, is based on certification authority architecture. The certification authority creates certificates, which are used to exchange public keys without contacting a public key server and avoiding thus, a possible bottleneck. Data is symmetrically encrypted with the use of blowfish algorithm [12] where the symmetric encryption key is negotiated in every session, using the public key RSA [13] algorithm. Digital signatures of the communicated data are appended to the encrypted plain message. The SHA1 hashing algorithm [14] along with the RSA algorithm is used to support the digital signature scheme.

In case of sending a data set, the result of the security layer, consisting of the encrypted data set, the digital signature and the certificate of the sender are forwarded to the socket layer.

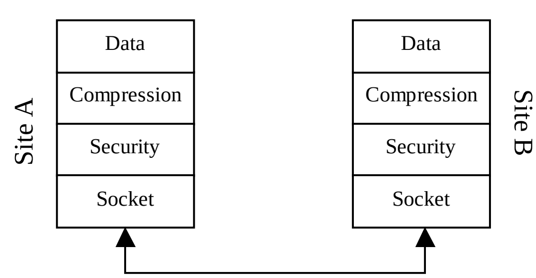

Fig. 1. Architecture of the data exchange service

Otherwise, the received data from the socket layer is manipulated, in order to verify sender's identity, to confirm the integrity of the received data and finally, to decrypt the compressed data set and forward it to the compression layer.

The socket layer is responsible for the establishment and graceful termination of a socket connection between two sites and the reliable communication of data over the connection.

B. On-line collaboration

The on-line collaboration in GALINOS VS follows the strict WYSIWIS (What You See Is What I See) [15] paradigm. WYSIWIS is a basic Computer Supported Collaborative Work (CSCW) paradigm, which recognizes that efficient reference to collaborating entities, depends on a common view of the application. As a result of the selection of the specific CSCW paradigm, a master/slave control relationship is employed, where the health care professional playing the role of the master is able to perform all actions of the VS, while the slave participant can only view the results of master's actions. The roles between the collaborative parties can change upon master's request, while any of the parties can end the session.

Following the design of the stand-alone VS application, the on-line collaboration can take place either on anatomical or beam description design. The initial step towards the strict implementation of the WYSIWIS paradigm is the transmission of the application status of the calling party (anatomical or beam description related data) to the remote one, during the establishment of the on-line collaboration session. The transmission is performed using the same architecture as the one employed in the off-line data exchange service, and the only difference in layers' functionalities is met in the data layer, which, in this case, is solely responsible for the retrieval and storage of the anatomical or beam design related data.

From this point further, and after the take-up of master’s role from one of the health care professionals, the collaborative environment forces the execution of all actions, which take place on the master's VS to the remote one. Since, only the directives for the actions, which have to be performed, are transmitted over the network and all the VS procedures are executed locally at every collaborating site, the delays caused by the network are minimised. Moreover, a parallel voice communication channel further supports the collaboration between the two parties.

Even though the messages exchanged during the on-line collaboration session do not contain information directly linked with identifiable patients, an extensive analysis of the communicated messages, could lead to assumptions regarding the treatment, which is going to be followed. Furthermore, the authenticity of the data should also be assured. Thus, security mechanisms must be employed, without having a significant impact on the interactivity of the on-line collaboration. Taking into consideration the required speed of electronic transactions during the tele-cooperative session, the negotiation of the symmetric key, along with electronic signatures and certificates, is done periodically during the tele-cooperation session, achieving a compromise between security and performance.

III. Results

For the purpose of evaluating the proposed collaborative environment, a pilot study has been performed, comprising the radiotherapy departments of four clinics. The VS of the GALINOS collaborative environment has been installed on PCs with double Pentium™ III processors at 600MHz and 256MB RAM, connected to the LAN of the radiotherapy departments, and configured to automatically receive data from the tomographic scanners and to export treatment settings in DICOM RT format. The communication between the collaborating departments has been supported by ISDN lines, and a single data channel (64 kbps) is allocated to a given connection.

A technical pilot study has been performed, aiming at the evaluation of the architecture design of the collaborative environment. The technical pilot study is based, in general upon quality assessment of system's functionalities and upon the monitoring of system's performance. The quality of the VS provided functionalities (imaging tools, calculation tools, etc.) during on-line collaboration is identical to the one of the stand-alone operation, since all procedures are executed locally.

In contrary, the evaluation of the collaboration environment performance is of high importance and has been realized by monitoring the amount of time required for the off-line communication of data sets, and the latencies, which are detected during the on-line collaboration. The average time periods required for various phases of the off-line communication of 44 data sets between distinct radiotherapy departments have been recorded and the results are shown in Table I, as a function of data sets’ size. The average time period dedicated to the initialization of the secure channel was 1.874 s, and includes the exchange of certificates between the collaborating parties, the secure communication of the symmetric key using the RSA algorithm (1024 bit) and the calculation / verification of digital signatures. The average throughput of the line regarding the encrypted communicated data was 60.583 kbps.

TABLE I

DATA SET SIZE AND TIME PERIODS DURING OFF-LINE COMMUNICATION

Compressed data set size	% of data sets	Encryption / Decryption of data (s)	Communication of encrypted data (s)
0 - 2MB	9%	0.203	254.875
2-4MB	23%	0.347	279.688
4-6MB	20%	0.582	298.121
6-8MB	16%	0.824	316.664
8-10MB	11%	0.990	339.430
10-12MB	16%	1.152	345.969
>12MB	5%	1.500	371.750

For the purposes of the evaluation of the on-line collaboration, all the events communicated during eleven collaborating sessions and the exact times of their execution have been recorded. During the monitoring periods, the average latency observed between the execution of the commands at the master's side, and the remote one, was 1.023 s. The maximum-recorded latency was 2.99 s, detected in the case of continuous rotations of 3-D surface rendering scenes.

IV. Discussion

The described evaluation study of the collaborative environment has been performed by the developers, in cooperation with health care professional of a few institutions, and was aiming at the verification of the implementation. The next step towards a complete evaluation study, includes the validation procedure of possible applications of the collaborative environment, investigating the level of satisfaction of users' requirements and needs. Two major application scenarios have been identified and their validation study is currently underway: the establishment of a collaborative network of health care professionals on VS, and the formation of a tele-educational framework on VS. A controlled effectiveness study and a cost-effectiveness study [16] are taking place for both applications.

V. Conclusion

The architecture of a CSCW environment has been presented enabling health care professionals to perform on-line collaboration on the design of radiotherapy treatment plans using a VS. The implementation of the proposed architecture, is based on the strict WYSIWIS paradigm and supported by a custom-built service for the off-line communication of data. Special attention has been given to security issues, based on the employment of encryption techniques, digital signatures and certificates. The evaluation of the collaborating environment indicated the suitability of the proposed architecture, since high interactivity has been achieved, without compromising the quality of the VS functionalities.

Acknowledgment

Financial support provided by the Greek General Secretariat of Research and Technology is gratefully acknowledged.

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